A New Type of Low Pass Filter With Defected Ground Structure

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A new design method of low pass filters (LPF) using defected ground structure (DGS) on planar transmission lines such as microstrip and coplanar waveguide (CPW) is presented. LPF is designed easily by extracting the equivalent circuit elements of unit DGS and compensating the line width of capacitive transmission line. The proposed LPF does not have any open stub, discontinuity elements such as Tee- or Cross-junction, and the repeated low-high impedance elements, which have been essential for design of conventional LPF. Only two DGS patterns and one transmission line with broadened width are used for design of the proposed LPF. Simple structure, small size (49% of a conventional LPF), less discontinuities, non-existing of the high impedance lines, no need for wire bonding required in CPW discontinuities, and high power handling capability are obtained through the proposed LPF.

INTRODUCTION

It is well known that periodic structures have typical low-pass properties. The representative periodic structures for microwave applications are various kinds of photonic bandgap (PBG) [1-4] and defected ground structure (DGS) [5]. DGS is also realized by etching off the defected patterns from the ground plane like PBGs. The basic DGS is composed of two wide defected areas and narrow connecting slot, which are the sources of the equivalent LC components, while the existing PBGs have inductive equivalent element only. DGS has simple structure, equivalent LC circuit model, and extensive applicability to design filters, couplers, dividers, and amplifiers [6-9].

A method to design low pass filters (LPFs) using DGS on microstrip substrate has been proposed already by [6]. In this paper, another scheme to design LPFs without open stubs, but only by using two DGS patterns and compensating the width of microstrip line.

The same method is applied to design a CPW LPF, too. There is no change in the width of signal line. No open stubs, high impedance lines, and junction elements such as Tee or Cross are required. This means wire bonding, which is essential for the CPW discontinuity elements, is not needed.

DGS PATTERN AND THE EQUIVALENT CIRCUIT ELEMENTS

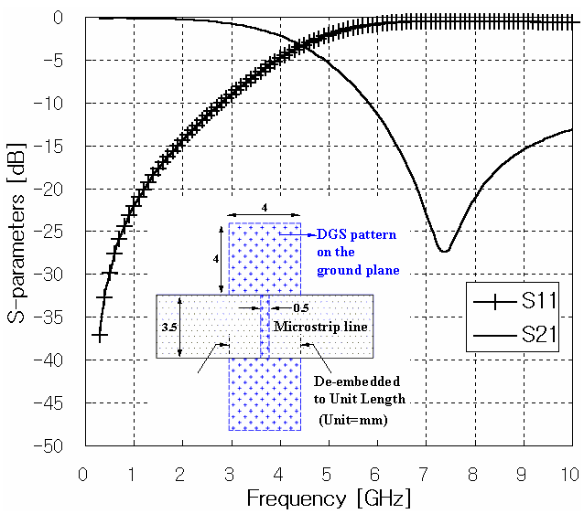

Fig. 1 Microstrip line with a dumb-bell shaped DGS pattern and characteristics by EM simulation. (ε_r=3.48, Substrate thickness=30mils)

Fig. 1 shows a microstrip line with dumb-bell shaped DGS and predicted performances by electromagnetic (EM) simulation. The shape of defect can be circle, octagon, etc. It is easily understood that there are equivalent L-C components as shown in Fig. 2(a) because the resonant and 3dB cut-off frequencies are observed in Fig. 1. Since the same properties can be seen from the 1-pole Butterworth prototype LPF [10], Fig. 2(b) is the equivalent to Fig. 2(a). Because two reactance values are expressed as (1) and (2), the equality at cut-off frequency should be preserved by (3).

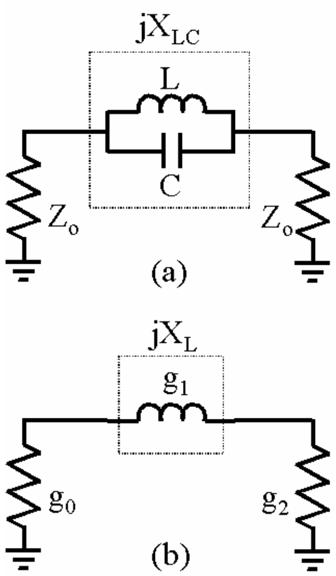

Fig. 2 (a) Equivalent circuit of the microstrip line with unit DGS (b) Butterworth prototype of one-pole LPF

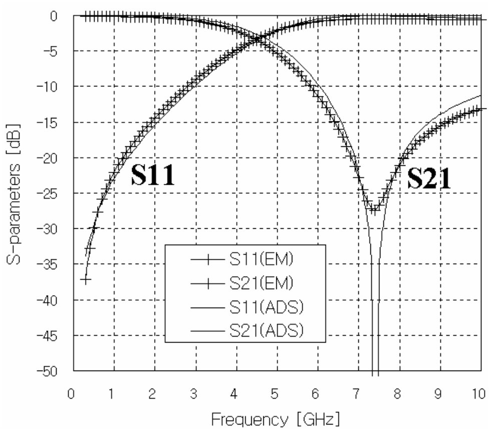

Fig. 3 Characteristics of the L-C network with EM simulation results overlapped.

$$X_{LC} = \frac{1}{w_o C\left(\frac{w_o}{w} - \frac{w}{w_o}\right)} \quad (1)$$

$$X_L = w' Z_o g_1 \quad (2)$$

$$X_{LC}\,|_{w=w_c} = X_L\,|_{w'=1} \quad (3)$$

where ω_0, ω', g_1, and Z_o are the resonant frequency, normalized cut-off frequency, prototype value of the Butterworth type LPF, and the scaled port impedance, respectively.

The extracted L and C are 2.2832 nH and 0.2026 pF. Fig. 3 represents the simulated characteristics of the parallel L-C network on Agilent Advanced Design System with EM simulation results overlapped. Good agreement is observed.

MICROSTRIP LPF USING DGS

A LPF with 0.01dB ripple can be designed using two L-C resonators and one shunt capacitor as shown in Fig. 4(a). This is one of typical topologies of LPFs. L1, C1, and C2 are 2.2832 nH, 0.2026 pF, and 1.5 pF, respectively. In order to realize the shunt capacitor, one open stub combined by Tee-junction or two open stubs connected by Cross-junction are required in conventional design [6]. However, in this work, it is realized by simple microstrip line with the compensated width as illustrated in Fig. 4(b). The width is fixed to have 3.5mm, which corresponds to the width of the 30 Ω microstrip line as has been depicted in Fig. 1. Length "G" has been chosen to have 5mm after the calculation of capacitance. Because the lower impedance of microstrip line, the more capacitive equivalently, open stubs and junction elements can be removed from the typical topology of LPF by increasing the width of microstrip line.

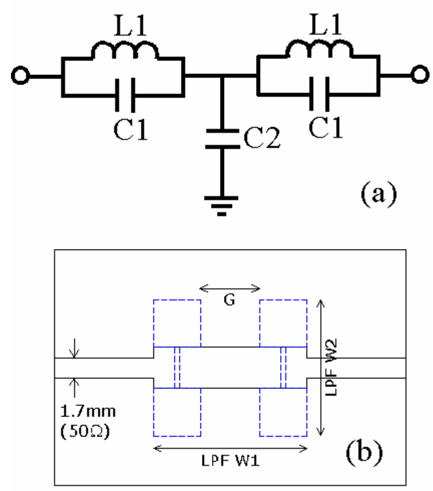

Fig. 4 (a) A typical LPF (b) The proposed LPF with two DGS patterns and compensated line width.

Fig. 5 shows the predicted and measured performances of the LPF. Although minor discrepancies are observed, the overall agreement has been achieved successfully. The weak discrepancies are caused by the mild interaction between DGS patterns, which are not contained in the schematic in Fig. 4(a).

"LPF W1" and "LPF W2" are the dimensions for the area of LPF itself, which exclude the 50 Ω feeding line for measurement, as shown in Fig. 4(b). The area of pure is 149.5mm^2.

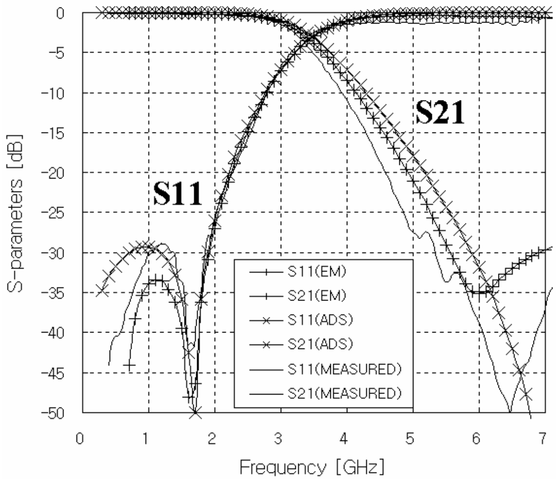

Fig. 5 Performances of the microstrip LPF.

Two conventional LPFs were designed for the purpose of comparison. The first LPF, shown in Fig. 6, has 3-poles and smaller size, 114.8mm^2, but its rejection slope is too loose. The second one, shown in Fig. 7, was designed to have 5-poles for the similar slope of rejection to the proposed LPF. However, its size is 307.8 mm^2, which is twice as large as the proposed LPF. In other words, the size of the proposed LPF is only half of the conventional design for the similar performances.

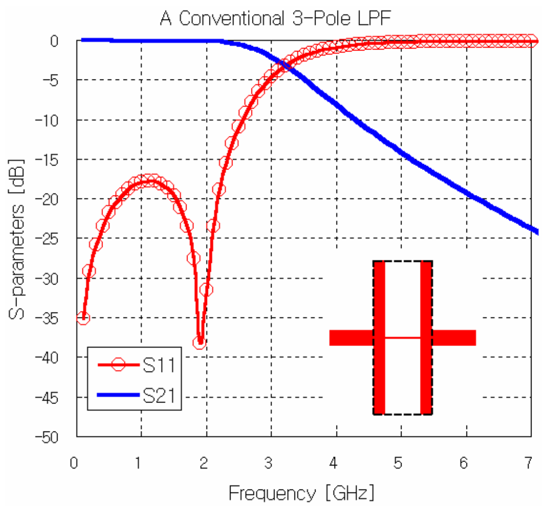

Fig. 6 A 3-poles LPF using a conventional topology.

Although there are two "Step" elements between the LPF area and 50 Ω feeding line, they are inevitable for measurement. In addition, the step discontinuities can be softened by adding taper- or triangle -elements to the step sections.

It should be noted that the highly increased width of the microstrip in LPF allows much high power to be handled. It is clearly compared that the widths of the series microstrip elements in the layouts of the proposed LPF and the conventional ones.

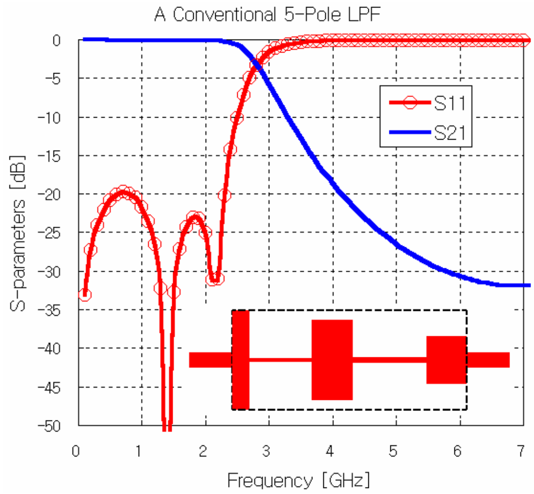

Fig. 7 A 5-poles LPF using a conventional topology.

CPW LPF USING DGS

The same design method can be applied to design a LPF using DGS on CPW ("DGSCPW") and transmission lines with lower impedance by narrowing the gap between the signal line and ground planes without touching the main signal line. This is great advantage because the width of signal line is constant. At least, there are no discontinuity elements in the main signal line in CPW structure. Only the gap are changed so that the line impedance is much lower than 50 Ω, for example 30 Ω in this work, by moving the ground plane towards to the signal line. Therefore the air-bridged bonding wires, which are essential in CPW discontinuity elements such as Tee- or Cross-junctions, are not required.

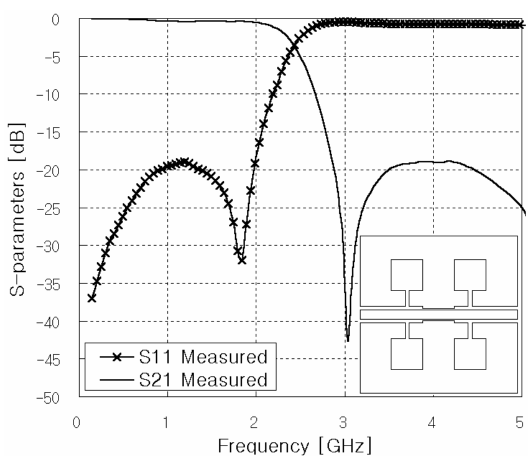

Fig. 8 Layout of the LPF using DGSCPW and measured performances. (ε_r=10.2, Substrate thickness=25mils)

Fig. 8 shows the layout of the LPF using DGSCPW, compensated line impedance, and measured performances. No open stubs and junction elements are observed. The width of the main signal line is constant. It is noted that a very steep rejection is achieved by using only two DGS patterns and capacitive line element. If a conventional LPF has the similar slope of rejection, the number of poles should be at least five approximately, as has been described in the microstrip case above. This is because there is considerable equivalent capacitance as well as inductance due to the narrow slots and wide defected area of DGSCPW, while the conventional CPW PBG proposed in [4] has the only inductive elements.

CONCLUSIONS

A new type of LPF using only two DGS patterns and one capacitively compensated transmission line is proposed. No open stubs, Tee- or Cross-junction elements, and bonding-wires are required. The width of the microstrip line was much larger than that of the port line impedance in the proposed microstrip LPF, while it was maintained untouched in the CPW LPF. This allows the proposed LPF to be suitable for very high power application. Additionally, the required area for the proposed LPF was only 49% of that of conventional design for the similar performances. The measured performances agreed well with the predicted ones. This proves the proposed LPF is an effective approach in design LPFs.

ACKNOWLEDGEMENT

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REFERENCES

[1] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, “Novel 2-D Photonic bandgap Structure for Microstrip Lines,” *IEEE Microwave Guide Wave Lett.* vol. 8, no. 2, pp.69-71, Feb. 1998.

[2] F.R.Yang, K.P.Ma, Y. Qian, and T. Itoh, “A Uniplanar Compact Photonic-Bandgap (UC-PBG) Structure and its Applications for Microwave Circuits,” *IEEE Trans. Microwave Theory Tech.*, vol. 47, No. 8, pp. 1509-1514, Aug. 1999.

[3] Q. Xue, K.M. Shum, and C.H. Chan, "Novel 1-D Microstrip PBG Cells," *IEEE Microwave Guide Wave Lett.* vol. 10, No. 10, pp.403-405, Oct. 2000.

[4] T.Y. Yun and K. Chang, “Uniplanar One-Dimensional Photonic-Bandgap Structures and Resonators,” *IEEE Trans. Microwave Theory Tech.*, vol. 49, no. 3, pp. 549-553, Mar. 2001.

[5] C.S. Kim, J.S. Park, D. Ahn, and J.B. Lim, "A Novel 1-D Periodic Defected Ground Structure for Planar Circuits," *IEEE Microwave Guide Wave Lett.* vol. 10, no. 4, pp.131-133, Apr. 2000.

[6] D. Ahn, J.S. Park, C.S. Kim, J. Kim, Y. Qian, and T. Itoh, “A Design of the Low-Pass Filter Using the Novel Microstrip Defected Ground Structure,” *IEEE Trans. Microwave Theory Tech.*, vol. 49, no. 1, pp. 86-93, Jan. 2001.

[7] J.S. Lim, C.S. Kim, J.S. Park, D. Ahn, and S. Nam, “Design of 10dB 90^o branch line coupler using microstrip line with defected ground structure,” *IEE Electronics Lett.*, vol. 36, no. 21, pp. 1784-1785, Oct. 2000.

[8] J.S. Lim, S.W. Lee, C.S. Kim, J.S. Park, D. Ahn, and S. Nam, “A 4:1 Unequal Wilkinson Power Divider,” *IEEE Microwave and Wireless Components Lett.*, vol. 11, no. 3, pp. 124-126, Mar. 2001.

[9] J.S. Lim, Y.T. Lee, J.H. Han, J.S. Park, D. Ahn, and S. Nam, “A Technique for Reducing the Size of Amplifiers Using Defected Ground Structure,” *2002 IEEE MTT-S Digest*, vol.2, pp.1153-1156.

[10] D. M. Pozar, *Microwave Engineering*, 2nd ed., John-Wiley & Sons, 1998. pp 422-496.